5-2014

Electrophysiological Cross-Modality Comparisons of Infant Individual Differences in Holistic Processing and Selective Inhibition

Matthew Singh
msingh4@utk.edu

Electrophysiological Cross-Modality Comparisons of Infant Individual Differences in Holistic Processing and Selective Inhibition

Matthew F. Singh

Greg D. Reynolds

University of Tennessee, Knoxville

Department of Psychology

Electrophysiological Cross-Modality Comparisons of Infant Individual Differences in Holistic Processing and Selective Inhibition

Abstract

Holistic, (global) processing refers to the integration of local stimulus features into a larger perceptual form with an interpretation independent of its parts. While global precedence is the norm for adults, infants' perception depends greatly upon individual differences. Using a novel auditory AX-CPT (AX Continuous Performance Task) this study examined congruence between auditory and visual holistic processing in 6 month-olds as measured by saccade latency and look duration. The task was designed so that holistic processing impaired performance. Results confirmed congruence between modalities with impaired performance of visual holistic-processors on trials which punished auditory holistic processing, despite previous findings of increased recognition memory in these infants. Current findings are explored in the context of a proposed inhibitory mechanism accounting for individual differences. Finally, computational models are explored, supportive of a first-order stochastic differential equation for changes in looking behavior across trials, similar to the Rescorla-Wagner model.

Introduction

Holistic, or global, processing refers to the gestalt integration of local elements. Adult research has found a general advantage (quicker response) in processing global configurations over the local elements of which they are composed (Navon, 1977; Kimchi, 1992). Although the order of processing may be influenced by things such as the approach-motivation and stimulus-induced affect (Gable and Harmon-Jones, 2010), under neutral conditions the effect is sufficiently constant that Navon (1977) proposed a global-precedence effect in adult visual processing, entailing that in the absence of interfering stimuli, adults tend to first perceive the global configuration before progressively localizing in to the finer elements. Moreover, recent research has found a similar effect in adult auditory perception (Bouvet, Rousset, Valdois, & Donnadieu, 2011).

In infants, however, processing order has been hypothesized to depend upon individual differences in intake strategy (Colombo, Mitchell, Coldren, & Freeseman, 1991) with most work focusing on look duration to a stimulus (e.g. Colombo, 1995). As a measure, fixation duration has demonstrated moderate overall reliability and among measures of attention, has been found to be the most stable across both short and long intervals (Colombo, Mitchell, & Horowitz, 1988; Colombo, Mitchell, Obrien, & Horowitz, 1987). More importantly, lower fixation duration has been linked to higher cognitive performance as measured in infancy (Colombo et al., 1988; Moss, Colombo, Mitchell & Horowitz, 1988), as well as later in childhood and into adolescence (Rose, Slater, & Perry, 1986; Tamis-LeMonda & Bornstein, 1989).

Infants exhibiting shorter looks, “short lookers” (Colombo & Mitchell, 1988, 1990) have shown greater recognition memory for a previous stimulus than “long-looking” infants

(Colombo & Mitchell, 1990; Colombo, Mitchell, & Horowitz; 1988; Colombo, Coldren, Mitchell, & Freeseman, 1991). From these results, Colombo (1995) proposed that shorter look durations are the result of a more efficient visual intake system. However, there have been two distinct hypotheses as to the basis of this difference.

Processing-strategy hypotheses (Colombo, 1995) conclude that the differences between short and long looking infants are the result of different stimulus-processing orders, with short lookers using the adult global-local processing sequence (Navon, 1977) and long lookers using a local-global processing sequence (Colombo, 1995). This hypothesis has been confirmed using a number of techniques, with particular emphasis on novelty preference in habituation paradigms (Colombo, Freeseman, Coldren, & Frick, 1991; Colombo, Frick, Ryther, & Gifford, 1996; Frick & Colombo, 1996; Stoecker, Colombo, Frick, & Allen, 1998). However, there have also been physiological bases, such as Guy, Reynolds, and Zhang's (2013) finding that short lookers only demonstrated amplitude shifts in event related potentials (ERP's) to novel global stimuli, while long lookers exhibited shifts only to novel local stimuli. Like adults, (Bruce & Morgan, 1975; Locher and Nodine, 1973) short lookers have also demonstrated an advantage in processing symmetrical over asymmetrical forms due to their global properties, while long lookers exhibited no change even with longer familiarization times (Stoecker, Colombo, Frick, & Allen, 1998).

The second hypothesis proposes that short and long lookers do not differ in processing order, but rather on processing speed (Colombo, 1995). A few studies using habituation paradigms have found that while short lookers quickly respond to the novel global stimulus as opposed to the novel local, given sufficient familiarization time long-lookers will also exhibit a global novelty preference either prior to the local novelty preference or exclusively (Colombo et al., 1991; Freeseman, Colombo, & Coldren, 1993), although these results have been inconsistent

(e.g. Colombo, 1995). Other studies that have not differentiated on looking style, have found early holistic processing as an ability of infants in general. For instance, Turati and colleagues (2010) found that infants as young as 3 months can demonstrate holistic processing of faces as evidenced by increased looking at misaligned facial portions (the composite face illusion).

However, McCall (1994) had a different explanation for the processing-speed results. Using the three looker groups distinguished by habituation patterns on multiple trials in five month olds (McCall, 1979), McCall (1994) demonstrated that while the group corresponding to roughly half of the sample that demonstrated short looks reached habituation faster, they also had the trial of longest look faster; almost immediately. Following the trial of longest look, he found that all habituation patterns (looker types) had the same decline in look duration and thus the same rate of processing (McCall, 1994). As a result, he concluded that what truly distinguished groups in the habituation paradigm studies (e.g. Colombo et al., 1991; Freeseman, Colombo, & Coldren, 1993) was that short lookers started processing *sooner*, not faster. This pattern has also been observed in other studies (e.g. Bornstein & Benasich, 1986). The greater explanative power of processing order over processing speed hypotheses may be seen in studies on sustained attention (e.g. Richards, 2003), in which sustained attention, refers to the state in which most encoding takes place. Using heart rate to measure the attentional states of short and long lookers, Colombo and colleagues (2001) found no difference in the proportion of time spent in sustained attention. In an ERP study, Reynolds, Guy, and Zhang (2011) also found no differences and concluded that differences in processing are the result of the selection aspects of attention (i.e. global vs. local) as opposed to the arousal aspects.

Still, the global-local processing sequence and the tendency of short lookers to more quickly exhibit the trial of longest look required explanation. McCall (1994) hypothesized that

the link between the two tendencies is inhibition. Infants with greater inhibition are likely to ignore the experimental surroundings and focus on the relevant stimulus sooner (McCall, 1994). Likewise, infants with greater inhibition can inhibit looks to previously processed stimulus components, while those with less inhibition might get "stuck" on a spot and keep processing the redundant information (McCall, 1994). Inhibition in this sense refers to executive inhibition, as opposed to less purposeful variants. A study demonstrating this distinction and its relation to global processing was done by Frick, Colombo, and Saxon (1999). Long and short looking infants were compared on their reaction times to localize a peripheral stimulus when it was presented either during the presentation of a central (competitive) stimulus or alone. When presented alone, looker groups did not differ in their ability to disengage and localize the stimulus, which could be considered a measure of less effortful, "stimulus-driven" inhibition. However on competition trials, short lookers demonstrated faster reaction times indicating that the true difference was in executive (endogenous) inhibition, which would be necessitated to shift fixation from the less salient stimulus, which analogs a previously processed local feature, to the more salient stimulus, which would relate to a local element not yet processed. Moreover, Holmboe and colleagues (2008), demonstrated the test-retest reliability of selective (executive) inhibition and found correlates between selective inhibition and frontal cortex tasks. Under a novel approach, the "Freeze Frame task", infants were encouraged to inhibit looks to peripheral distractors either with an engaging or repetitive central stimulus and were punished for looks at peripheral distractors with a temporary freezing of the video central stimulus. In line with the findings of Frick, Colombo, and Saxon (1999), the tendency to inhibit peripheral looks during the repetitive (non-competitive) central stimulus had no correlation with frontal cortex tasks. However, there was a correlation between frontal cortex scores and selective (executive)

inhibition, as measured on trials with the engaging (competitive) central stimulus. Holmboe and colleagues (2008) also noted that there were large individual differences in selective inhibition, with one group successfully demonstrating it while the other did not. Moreover the study found that selective inhibition at 9 months predicted performance at a 24 month retest.

Under Treisman and Gelade's (1980) "feature-integration theory of attention", focal attention connects the separate local elements of a stimulus into a coherent gestalt. Thus with poor executive inhibition, long looking infants are impaired in their focal (or effortful) attention. This theory of attention also explains the observance of short looking infants to distribute their attention more broadly during familiarization and engage in many short glances as opposed to few long ones (Bronson, 1991).

However, long lookers can still be made to perform identical to short lookers on global habituation paradigms. Jankowki, Rose, and Feldman (2001) familiarized infants to a stimulus separated into four quadrants. With the initial presentation of a novel global stimulus only short lookers habituated. However, using lights to sequentially highlight the quadrants, Jankowski and colleagues were able to shift long lookers visual focus. When presented with a novel global stimulus, these long lookers performed identically to short lookers, indicating that the processing differences are indeed due to the diminished ability of long lookers to inhibit looks to the previously processed familiar local section. It may be that a further reason for the lack of local processing precedence in long lookers in Colombo et al. (1991) is that the local discrimination task used the letter "C" as the familiarization stimulus and "G" as the novel local. Had local-processing infants been focused on any part other than the small section that changed, they would have perceived no difference. Were a long looker to focus initially on an invariant part of the stimulus, the "local" change would not be noted until the infant and exhibited executive

inhibition to switch focal points to the part that did change, thus actually exhibiting global processing.

In physiological studies, the main region of interest in attention is the prefrontal cortex and specifically the dorsal lateral prefrontal cortex and anterior cingulate cortex (Posner & Peterson, 1990). In adult ERP analysis, processing of global over local is related to the N2 and P3 components, with longer peak latencies for local processing (Han, Fan, Chen, & Zhuo, 1997) indicating that the system responds quicker to global processing tasks. The Nc, an infant ERP component, has been hypothesized to be a precursor to the adult N2 (Karrer & Monti, 1995; Nelson & Dukette, 1998) and source localization analyses have found the prefrontal cortex to be a likely source for the Nc (Reynolds & Richards, 2005; Richards, Reynolds, & Courage, 2010).

Other studies have also found the development of the prefrontal cortex to be linked with working memory and inhibitory control in both infants and children (Casey et al., 1995; Diamond, Prevor, Callender, & Druin, 1997; Luciana & Nelson, 1988). During infancy, the frontal lobe in general, undergoes rapid structural changes due to synaptogenesis, myelination and growth of axons, and increased metabolism (Chugani, Phelps, & Mazziotta, 1987; Deoni et al., 2011; Tsekhmistrenko, Vologirov, Vasil'eva, & Shumeiko, 2004). Maturation of the frontal lobe and especially the prefrontal cortex provides the necessary resources to support higher cognitive functions (Colombo & Cheatham, 2006). A number of studies have confirmed prefrontal function using the A-not-B task.

In the A-not-B task, participants must reach towards a hidden object. After several successful reaches with the object being hidden in the same location, the location is changed and the infant must reach towards the new location, a task which involves both working memory and

executive inhibition to refrain from reaching to the previous location (Diamond, 1990). In lesion studies of primates, A-not-B performance was shown to depend upon the integrity of the dorsal lateral prefrontal cortex (Diamond, 1990; Diamond & Goldman-Rakic, 1989). However lesions of the dorsolateral prefrontal cortex have no effect on the ability of primates to use simple working memory or simple inhibition (Diamond, 1990). Rather, the dorsolateral prefrontal cortex's main role appears to be in the integration of working memory and executive inhibition (Diamond, 1992).

Most infants cannot solve the A-not-B task before 5-months (Cuevas & Bell, 2010). However between 7.5 and 8 months individual differences appear, with approximately half of infants able to solve the task at this point (high performers) (Bell & Fox, 1992; Diamond, 1985). Cuevas, Bell, Marcovitch, and Calkins (2012) have proposed that the change represents maturation of the prefrontal cortex, similar to the increase in working memory capacity due to frontal myelination (Klingberg, Forssberg, &Westerberg, 2002; Nagy, Westerberg, & Klingberg, 2004; Wolfe & Bell, 2004, 2007). Using EEG, Bell and Fox (1992) found that high performers on the reaching A-not-B task showed relatively greater increase in baseline frontal EEG power, which Nunez (1981) speculated to reflect the organization and excitability of a neuronal cluster. However there were no EEG changes associated with performance on a simple inhibition task. In addition Bell and Fox (1992) found increased anterior/posterior coherence, a measure that is related to number of axonal connections and the white matter density of those axons (Nunez, 1981; Thatcher, Krause, & Hrybyk, 1986). On a looking version of the task Bell (2001) found that high performers had task related increases in EEG power at frontal and posterior locations, while low performers exhibited no change.

Taken together, both looking and A-not-B performance data suggest that approximately half of infants demonstrate more mature function of the prefrontal cortex, especially at dorsolateral locations. In addition, the A-not-B EEG data indicate that this might coincide with superior connectivity between frontal and posterior locations (Bell & Fox, 1992). Among older children, Rueda and colleagues (2005) found that the executive attentive network, which includes inhibitory control (executive inhibition) has a large genetic determinant in dopaminergic alleles, especially for DAT1 (Dopamine transporter 1), which may play a role in executive attention (Fossella et al., 2002). Rueda and colleagues (2005) also found that participants with the long form of the DAT1 gene had higher scores for effortful control, and had more mature ERP patterns for the N2 wave. In contrast, Although DAT1 polymorphisms have their greatest effect in the striatum, Holmboe and colleagues (2010) proposed that they may affect performance on a task of executive inhibition through frontal-subcortical circuits. However, the effects seem to depend upon combination with other dopamine gene polymorphisms. Using the Freeze-Frame paradigm (see Holmboe et al., 2008), Holmboe and colleagues (2010) found that the *COMT* (catechol-*O*-methyltransferase) Met/Met genotype only predicted higher executive inhibition in infants without two copies of DAT1 10R. In many aspects the Freeze Frame paradigm mirrors the peripheral task used by Frick and colleagues (1999), in which short lookers were found to exhibit greater executive inhibition. Likewise, other studies have suggested an association between DAT1 and response inhibition (Cornish et al., 2005). However, the complexity of dopaminergic gene interactions is such that while DAT1 10R homozygotes have demonstrated superior performance in the Rueda et al., (2005) study, 10R is generally considered a risk allele with other studies linking the 10R allele to impulsivity in ADHD (e.g. Gizer & Waldman, 2012) and lower educational achievement (Vaughn, Delisi, Beaver & Wright, 2012),

making striatal genetic influences on prefrontal indices particularly confounding. However, the role of dopamine in the executive attention/inhibition system is relatively clear. Although the adult attention system itself is mostly under cholinergic control (for a review see St□rmer, Passow, Biesenack, & Li, 2012), there are still dopaminergic interactions and considering the lower organization and specialization found in infant frontal cortical regions it may be that these neurochemical systems overlap even more. Finally, animal studies (e.g. McCulloch, Savaki, & Sokoloff, 1982) have found that the dopamine antagonist Haloperidol interrupts glucose metabolism in prefrontal cortex. Thus it may be that dopaminergic pathways influence how quickly prefrontal areas develop through metabolic processes (see Diamond, 1996).

One further role of dopamine in dorsolateral prefrontal cortex is contextual processing (see Cohen & Servan-Schreiber, 1992 for a review). Contextual information refers to the information captured from prior stimuli that is held as an internal representation to direct future responses (Cohen, Barch, Carter, & Servan-Schreiber, 1999; Cohen & Servan-Schreiber, 2002). As contextual information is taken from the whole environment it may provide a more complete representation of holistic processing than simple stimulus features. The ability of infants to use contextual information has been well recorded and has been shown to influence infant behavior as early as 3 months (Butler & Rovee-Collier, 1990; Rovee-Collier, Schechter, Shyi, & Shields, 1992). In a series of studies, Rovee-Collier and colleagues demonstrated the importance of contextual information on memory retrieval using the mobile conjugate reinforcement task. In this procedure, two groups of infants were trained to move a mobile (the reinforcer) through kicks, with retention measured at both short (2 days) and long (7 days) intervals. The first group used the same crib bumper (context) during retention tests as during training, while the second used a different bumper. While at short intervals retention was demonstrated by both groups, at

long intervals only the congruent context group demonstrated retention, indicating the role of contextual information in infant memory retrieval. In an auditory study, Fagen and colleagues (1997) replaced crib bumpers with various musical selections and found the same result, suggesting that even early in infancy, contextual processing is highly developed in both the auditory and visual modalities.

If contextual processing is modality independent, it may be that the more specific holistic processing of stimuli may be modality independent as well, and thus auditory and visual holistic processing would engage the same neural circuitry. For example, an adult fMRI study by Levitin and Menon (2005) found that when presented with unfamiliar highly structured (enabling gestalt integration) and scrambled (disabling integration) musical pieces, participants only displayed high activation in the ventral prefrontal cortex for the highly structured pieces, possibly indicating that this area plays a role in auditory holistic processing as well.

However, while general environmental-contextual processing is early developed in both modalities, it may be that the gestalt integration of auditory stimuli contains similar individual differences as the visual modality. In general, "holistic" auditory processing involves the integration of local auditory patterns across temporal relations (i.e. rhythmic patterns or sequences), as opposed to the spatial-temporal relations of global processing. In 7 and 9 month-old infants, the ability to categorize auditory sequences based upon rhythm and tempo has already been demonstrated (Trehub & Thorpe, 1989). In a study by Kobayashi, Hiraki, & Hasegawa (2005) 6 month-old infants demonstrated the ability to match the number of tones presented with the number of visual stimuli presented on a violation-of-expectation paradigm, irrespective of the rate or duration of tones presented. However, while numerosity is a natural relationship, individual differences begin to appear in the holistic processing of artificial

relationships. Lewkowicz (2004) found that when linking the natural relationship between the visual impact of an object and the production of sound, 4-month old infants were unable to detect changes in the sequence of auditory and visual stimuli, both separately and in combination. However, when this natural relation was blocked, 4-month olds as a group only demonstrated recognition of order changes in the combination of auditory and visual sequential changes, individual differences were manifest when modalities were presented separately and particularly in the only-auditory change condition. In fact, individual differences were so great that while the mean response recovery to the auditory-only condition was roughly twice that of the (significant) audiovisual condition, the standard deviation was so large that the group response failed to meet significance. As the 8-month old group demonstrated significant response recovery in all conditions, it is possible that these differences reflect differing degrees of maturation in the younger sample. However, the disappearance of individual differences in audiovisual combination changes may be due to a general early ability of infants to process amodal (artificial) relationships. For instance, one study found that even newborns could learn arbitrary auditory-visual associations with amodal contingency, while failing to do so in the lack of a contingency between modalities (Slater, Brown, & Badenoch, 1997). Individual differences have also been found in temporal estimation (Colombo & Richman, 2002), a process suggested to involve frontal cortical structures, particularly prefrontal cortex (Dietrich, Frederick, & Allen, 1997).

Combining these aspects of modality-independent holistic processing, researchers in the current study examined looking measures on a modified auditory AX version of the continuous performance task (AX-CPT). In the AX-CPT, participants are instructed to respond only to the sequence of A followed by X, with each response scored as a hit or miss. Although the AX-CPT

has been primarily used to study contextual processing (e.g. Cohen et al., 1999), other studies have used it to measure attention and impulsivity (e.g. Gizer & Waldman, 2012). In this study, the further aspect of holistic stimulus processing is added. As all stimuli will be auditory, gestalt integration will be required to process the AX sequence as a single unit, as opposed to the separation of individual stimuli due to local processing. However, the AX-CPT implemented in this study included a switched-order (XA) condition. This method allowed discrimination between component and order based holistic processing. In an order based holistic processing, memory stores should contain both components and the relation (temporal) between the two, while a simple component based processing approach would predict decreased performance as the coding of both components without a conscious representation of temporal relations should fail to distinguish "AX" and "XA". Finally, the much high proportion of the "AX" sequence relative to others should lead to a pre-potent bias for "AX". In this case, one would expect that lower inhibition and working memory would result in long lookers displaying a strong "AX" bias.

To measure sequence identification, the AX sequence corresponded to the appearance of a highly salient video with sound on one side of a computer monitor facing the infant, while all other combinations resulted in the appearance of a similarly salient stimulus on the opposite side. Direction of anticipatory looking and saccade latency were used to measure stimulus predictions.

Method

Participants

The final sample of participants will consist of 30 infants aged approximately 6 months (25-27 weeks after birth). Presented results are based on an initial sample size of 8. As with previous studies in our lab, infants primarily came from middle to upper class, Caucasian families (Reynolds, Guy, & Zhang, 2011). Exclusion criteria consisted of less than 38 weeks gestation, birth complications, and birth weight below 2.5 kg (approximately 5 lb, 8 oz.). One infant was unable to originally complete testing due to fussiness and was retested within a week.

Apparatus

The apparatus was similar to that used by Guy, Reynolds, and Zhang (2013). Participants were positioned in a parent's lap 55 cm away from a 27' color LCD monitor (Dell 2707 WFP) and at approximate eye level with the monitor. The seating area was surrounded on all sides by black curtain, except for the side behind the participant and the room remained unlit throughout testing. Looks were recorded using a digital camcorder (Sony DCR-HC28) located just below the monitor and the video recorded through Netstation software, Electrical Geodesics Incorporated (EGI; Eugene, Oregon). Netstation was used in recording EEG/EOG data and synchronizing the EEG/EOG and video data. A Dell Workstation in the control room used to run experimental protocol and A/V input to the monitor using E Prime.

Stimuli

Two types of **visual stimuli** were used in the course of this study. A **Female face** subtending a 20^{o} square was presented on the monitor for the initial designation of looking groups. The **Reinforcer** consisted of an image of "Big Bird". Additional sesame street clips were briefly displayed before trials when infants became bored or fussy.

Auditory Stimuli consisted of four auditory sequences created from a pool of 4notes. Each sequence was composed of a 600ms tone followed by a 400 ms ISI and a second 600ms tone. Sequences are represented as AX (target) and XA, BY, and AY (standards).

EEG/EOG recording

EEG/EOG recording were similar to that used by Guy, Reynolds, and Zhang (2012). All data was collected using the EGI Geodesic EEG System 300 (GES system). The system consists of both the Netstation recording program and the NetAmps hardware, in addition to the sensor net. Although the GES system's Hydrocel Geodesic Sensor Net contains 128 channel, only 126 were used, with 124 for EEG net and 2 for the EOG electrodes. The remaining channels were connected with low resistance wire to decrease noise. Each of the 124 net channels corresponds to a "pedestal" consisting of an electrode and a sponge for the absorption of electrolytic fluid, enabling recording without abrasion techniques or gels. Pedestals are arranged in a standard geodesic configuration with elastic interconnections to assist in conforming to different skull shapes. Average inter-electrode differences were 21mm. Prior to use, the net was soaked in an electrolytic solution for 10 minutes. EOG electrodes were coated with the conductor Signa Crème (Parker Laboratories; Fairfield, NJ) and attached using adhesive collars.

Electrode impedances typically ranged from 10-50KΩ and the EGI system used high-impedance amplifiers. The amplifier contained 128 channels and was connected to a PowerPC Analog to Digital (A/D) converter. The Netstation software provided in the GES system was used in EEG/EOG recording with a sampling rate of 250Hz with 20K amplification. During recording, band pass filters were set from .3-100Hz. Netstation software was also used for data storage, measuring electrode impedances, temporally synchronizing communication between the two computers, and conducting zero/gain calibration for each electrode.

Procedure:

Participants were presented with a female face until breaking fixation after 20s of accumulated looking. Participants were then presented with a randomly selected auditory sequence followed by a 300 ms inter-stimulus interval (ISI) before the presentation of the reinforcer. The AX sequence signaled appearance on one side (counterbalanced) while all others signaled the opposite side of the screen. To prevent laterality bias, the AX sequence occurred 3 times as often as the others. Data collection proceeded until the participants became bored or fussy (M=70 trials, SD=17).

Analyses

Electrophysiological analyses were performed using the NetStation software provided with the EGI system. Bad segments were manually removed for either poor recordings or participants looking away during stimulus presentation. “Hits” and “Misses” were defined as

either correct or incorrect anticipatory looks for the visual reinforce and were sorted by trial type. Latency data was filtered for a 100-500ms prosaccade band pass. Latency data was not collected for "Hit" trials. As analyses of total trials completed found that short lookers completed more paired-trials (M=41.25, SD=4.19) than long lookers (M=26.5, SD=4.36; t(6)=-4.877, p=.003 2-tailed). For this reason, data beyond paired-trial number 30 were discarded in latency analyses. Following each regression analysis additional filtering was done to remove influential observations based upon the criteria Cook's D > 4/n (Bollen & Jackman, 1990). To analyze behavioral (anticipatory look) data we used a modified Receiver Operating Characteristic (ROC) measure. Discriminability was defined as:

$$\frac{Hit-False\ Alarm}{\sqrt[2]{Hit+False\ Alarm}}. \quad (1)$$

In the case of ROC for the target ("AX"), Hits would refer to correct anticipatory looks on AX trials while False Alarms would refer to incorrect anticipatory looks on standard trials.

The square root in the quotient's denominator was used to bidirectionally amplify effects for infants with more total anticipatory looks as the conventional ROC curve and sensitivity index (d') are based on forced choice paradigms. For latency data we considered look latency during associative learning to be a first-order stochastic differential equation with two subject dependent parameters (α, β), a task dependent parameter (λ), and a noise term (ξ) based upon Rescorla-Wagner (RW) learning (Rescorla & Wagner, 1972).

$$\frac{dx}{dt} = (\alpha + \beta)(\lambda - x) + \xi \quad (2)$$

In order to compare changes in relative latency across groups we set "x" as the proportion of standard over total latencies (Lagged Latency Ratio; LLR) on a given trial pair. The discrete form then becomes:

$$\left(\frac{L_S(t+1)}{L_S(t+1)+L_T(t+1)}\right) = (\alpha + \beta + 1)\left(\frac{L_S(t)}{L_S(t)+L_{T(t)}}\right) + (\lambda + \xi) \quad (3)$$

Finally we defined an additional measure ROCm for the standard as:

$$\frac{Hit_S - Miss_T}{Hit_S + Miss_T + Hit_S + Miss_T} \quad (4)$$

This measure was only used as a parameter in the latency equation as a combination of both discrimination and total response.

Regression analyses were performed using the JMP 10 interface for SAS while mean-comparison tests were performed in SPSS 21 (IBM).

Results

Descriptive statistics for anticipatory looking behavior are displayed in Table 1.

For behavioral measures, the ROC (discrimination) functions for standard stimuli were positively correlated with peak look ($r(1, 6) = .732$, $p=.039$ 2-tailed), but not for the target (see Figure 1). Cook's D filtering did not affect significance. Mean comparisons found that long lookers had fewer total misses on target trials ($t(6)=2.501$. $p=.046$, 2-tailed) and, likewise were more accurate on target trials (see Figure 2, left) as measured by target misses over total anticipatory target looks ($t(6)=3.534$, $p=.012$, 2-tailed). However, the discriminability differences

were not significant, although there was a trend for short-lookers to have lower discriminability (see Figure 2, right) for targets (t(6)=-2.034, p=.088, 2-tailed).

To decompose the factors of peak look, exploratory regression analyses were performed with respect to standard ROC for behavior and standard ROC for latency. Because peak look was expected to be strongly related to long latencies and number of trials, separate analyses for each filter type were performed and presented in Table 2. Note that the presented results all followed Cook's D filtration whereas, prior to outlier removal, many contained latency components significant at the 2-tailed level. As the direct relationship between latency and peak look was not specified a-priori, results are purely exploratory and indicate that a further latency component to the peak look-behavioral relation is only significant in accounting for extreme values, as indicated in the contour density mapping (Figure 3).

In testing our computational model of a first order, linear stochastic differential equation, multiple regression analyses were performed on the proportion of standard over total latencies for a given trial. Model comparisons supported a linear differential equation with predictive factors ROC standard and looker type. More specifically the adjusted standard latency (F(2,48)=14.958, p=<.0001 2-tailed, ω^2=.358) was negatively correlated to ROCm*LLR on the previous trial (t=-2.92, p=.0053 2-tailed) and with the LLR on the previous trial (t=-5.43, p=<.0001 2-tailed).

To further explore the effect of looker type, separate models were created for each looker group. For long lookers, the product of ROCm and LLR remained predictive of subsequent latency ratios (F(2,18)=10.117, p=.0011, 2-tailed, ω^2=.477). While the product of ROCm and LLR remained negatively correlated (t=-3.27, p=.0042 2-tailed), the un-parameterized LLR

(previously lookertype*LLR) was now positive (t=2.46, *p*=.0241, 2-tailed). In contrast, for short lookers (F(2,27)=6.332, *p*=.0056, 2-tailed, ω^2=.269) the product of ROCm and LLR, while still negative, was no longer significant (t=-.60, n.s.), while the un-parameterized lagged latency ratio remained negative (t=-3.04, *p*=.0052, 2-tailed). After removing the insignificant ROCm product, short lookers maintained a negative coefficient for lagged latency ratio (F(1,28)=12.596, *p*=.0014, 2-tailed, ω^2=.31). The same was done for long lookers, who maintained a positive coefficient (F(1,19)=6.310, *p*=.0212, 2-tailed, ω^2=.249). Finally, these were combined in an additional simple regression using only the looker-label*LLR interaction found that, for short lookers, previous adjusted standard latency negatively predicted subsequent standard latencies (*Pearson's r*(48)=-.464, *p*=.0007, 2-tailed).

Discussion

As expected, long-looking infants outperformed short looking infants in standard trials for behavioral measures (discriminability). For anticipatory looking, standard discriminability was a positive function of peak look duration, indicating that longer-looking infants were better able to discriminate between AX and alternatives (most likely due to a lack of the AX-XA interaction). However, the relative latency for standard trials could be decomposed to a first order function of directly previous latency and with looker-type and behavioral ROC's as multiplicative constants. In all cases these constants were negative indicating a general trend toward lower standard latency relative to target which was amplified in short-lookers.

These results are interesting in that while short-lookers had lower standard discriminability as indicated by behavioral measures, latency measures indicate relatively quicker responses for standard stimuli. Overall, it appears that long-lookers tended toward the

prepotent response of target stimuli. While results support an AX-XA interaction interfering with short-lookers ability to discriminate target and standard stimuli, their relative latency differences indicate increasing facilitation on standard trials relative to targets. This may be due to decreasing strength of the prepotent (target) representation or further learning of non-interactive standard values (e.g. BY) whereas long-lookers either focused solely on the prepotent stimulus (target) or their memory representations of standard stimuli decayed more rapidly. It might also be that the impaired discriminability of short-lookers led to further attentional allocation on those trials which featured XA stimulus, similar to violation of expectations, although this explanations implies that they did indeed discriminate AX-XA as increased attention to all "A" and "X" forms would favor the more common order (AX). Finally, the greater proportion of AX vs. XA trials may have caused a relatively greater presence of interference in target trials. However, even when removing the ordering factor, compounds containing "A" and "X" should be probabilistically more predictive of the target reinforcer as the AX sequence occurred three times as often as XA. Thus the finding that short-lookers did not demonstrate a probabilistic slant towards the target on AX trials indicates an overall interference effect greater than that of the associative strengths. It may be then, that short-lookers did not demonstrate any overt learning in the presence of interference. Latency data, however, indicates a main effect of standard learning, possibly reflecting the non-interactive trials. For this reason, no general conclusions can be made without analysis of data for each stimulus, rather than each reinforcer to dissociate XA interactions from BY and AY associations.

Should XA trials differentially impair performance between looker-groups, data would support an AX-XA interaction implicating WM stores as critical in differential performance. In contrast, a null effect of stimulus subtype would implicate inhibition of the prepotent response

(target) as critical in between-group differences. However, specific stimulus interactions are also important in long-looker data. Although long-lookers had far fewer misses on target trials (and shorter target latency) they did not differ in any other aspect. The lack of difference in standard misses refutes a possibility of laterality bias in response, hence the prepotent response (target) was not active on every trial. This leads to two, possibilities. The first is that long-lookers fully learned the target association without significantly learning the standard. If long-lookers learning depended solely upon the presence of the component (X) and only made predictions based upon the final component, there should be no effect of standard stimulus type. The second possibility is that long-lookers only learned the "X" association but made predictions based upon the sum of individual components (see Andrew & Harris, 2011), hence, in XA trials, the prepotent X association and prediction would continue even after the presence of "A". If "A" had a learned association, these would be competing responses, while a lack of "A" learning would only lead to the decay of "X" association over time and attentional demands, as in the leaky competing accumulator model (Usher & McClelland, 2001). In the former case, the removal of XA trials would lead to evidence of learning on standard trials, whereas in the latter case, XA trials would have the worst performance, but other standard trials would still not evidence discriminability or learning.

In addition to the inability to discriminate interactions of individual stimuli, the current results are limited by the small sample size, which greatly limits generalizability. Moreover, the present design of using AX vs. XA introduces a number of confounds into the design which limit the ability to isolate a measure of inhibition as holistic processing. The lack of hierarchical compounds using other stimulus combinations results in a lack of comparison for the AX combination, while identically perfect performance can be achieved by learning only the final

stimulus component or through passive holistic processing, combined with strong inhibition. Furthermore, the AX vs. XA analysis is limited upon simple Pavlovian associations in compounds without a concept of order, which may not be a valid assumption in even young infants (Kirkham, Slemmer, & Johnson, 2002). Finally, the mechanical properties of the auditory system itself (such as resonant frequencies) give rise to perception of changes in components. For this reason, two-tone combinations could be uniquely identified by the perception of change/shift which would be difficult or impossible to control for. The pre-existing evidence of rhythmic matching in slightly older infants (Trehub & Thorpe, 1989) makes this confound of particular relevance. Future studies may benefit from the implementation of a standard fully crossed AX-CPT (AX, BX, AY, BY) which would eliminate many of the confounds inherent in the modified. In addition to perceptual research, similar findings may be of use in the development of skills such as statistical learning and speech development (Hay & Lany, 2012).

Funding

This study was funded an internal grant from the Chancellor's Honors Program at the University of Tennessee, Knoxville to MS.

Conflicts of Interest

The authors report no conflicts of interest.

FIGURES AND TABLES

Table 1. Anticipatory Looking and Discrimination by Looker Type

	LookerType			
	L		S	
	Mean	Standard Deviation	Mean	Standard Deviation
TrHit	3.25	3.30	3.50	1.00
TrMiss	.25	.50	3.75**	2.75
StHit	1.75	1.71	2.50	1.29
StMiss	2.75	2.63	3.50	.58
TotalBehavior	8.00	4.40	13.25	4.43
ROCTr	.09	.24	-.01	.07
ROCSt	.33	.38	-.08*	.12
ROC.TvS	-.24	.37	.06	.15

** p<.05 (2-tailed)

*p<.1 (2-tailed)

Figure 1. Plot of Standard discriminability as a function of Peak Look

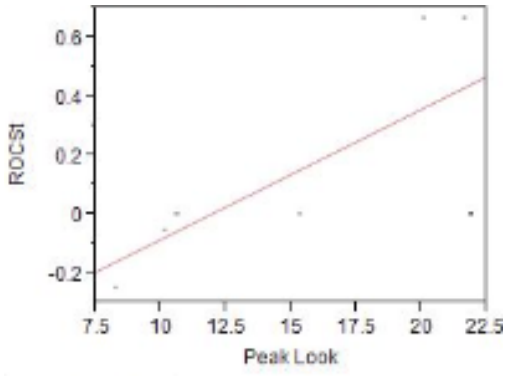


Figure 2. Comparison of Anticipatory looking (left) and discriminability/ROC (right) grouped by looker type.

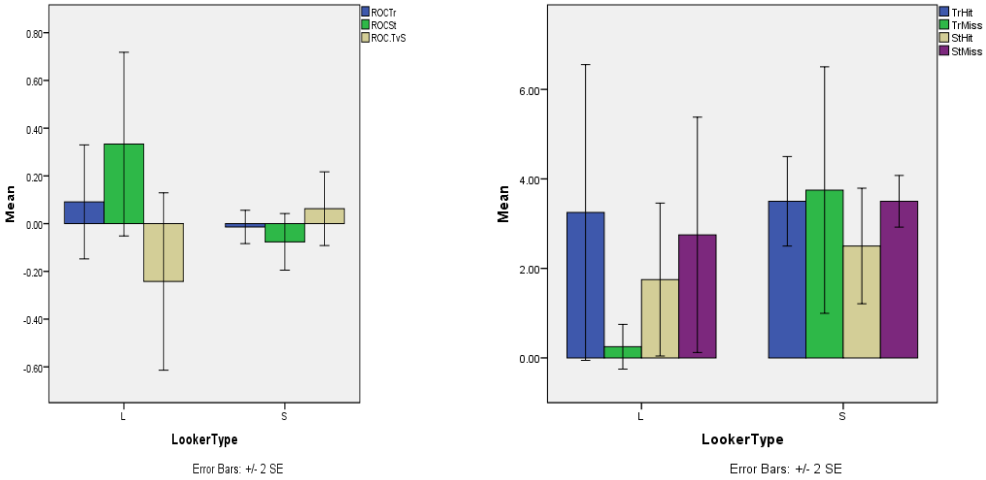
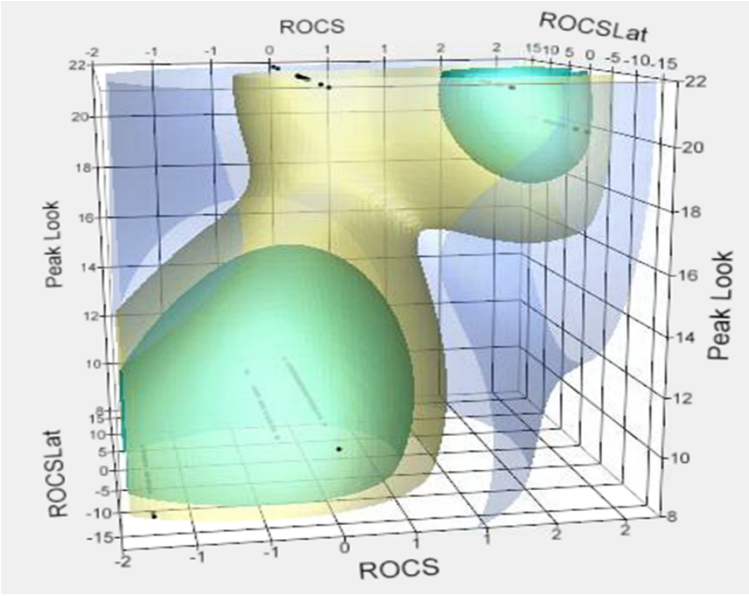


Table 2. Model fit of Peak Look vs. Behavioral (anticipatory looking) and Latency measures by filter type.

	No Trial Filter			Trial Filter		
	No Latency	High Pass	Band Pass	No Latency	High Pass	Band Pass
	.656, n=124 p<.0001	.647, n=111 p<.0001	.637 n=105 p<.0001	.573, n=110 p<.0001	.631 n=95 p<.0001	.626 n=90 p<.0001
Behavioral	t=15.21, p<.0001	t=14.20 p<.0001	t=13.51 p<.0001	t=12.05 p<.0001	t=12.72 p<.0001	t=12.02 p<.0001
Latency	t=-1.74 p=.0844	t=-1.76 p=.0810	t=-1.53 p=.1282	t=-1.48 p=.1407	t=-1.46 p=.1468	t=-1.33 p=.1880

Figure 3. Contour Density Mapping of Peak Look as a function of behavioral ROC and latency ROC



References

Andrew, B.J., Harris, J.A. (2011). Summation of reinforcement rates when conditioned stimuli are presented in compound. *Journal of Experimental Psychology: Animal Behavior Processes, 3*(4), 385-393

Bell, M.A. (2001). Brain electrical activity associated with cognitive processing during a looking version of the A-not-B task. *Infancy, 2*, 311-330

Bell, M.A. & Fox, N.A. (1992) The relations between frontal brain electrical-activity and cognitive development during infancy. *Child Development, 63*(5), 1124-1163.

Bell, M.A. & Wolfe C.D. (2007) Brain reorganization from infancy to early childhood: Evidence from EEG power and coherence during working memory tasks. *Developmental Neuropsychology, 31*, 21–38

Bollen, K.A. & Jackman, R.W. (1990); *Regression diagnostics: An expository treatment of outliers and influential cases*, in Fox, John; and Long, J. Scott (eds.); *Modern Methods of Data Analysis* (pp. 257-91). Newbury Park, CA: Sage

Bornstein, M.H., & Benasich, A.A. (1986). Infant habituation: Assessment of individual differences and short-term reliability at five months. *Child Development, 57*(1), 87-99

Bouvet, L., Rousset, S., Valdois, S. & Donnadieu, S. (2011). Global precedence effect in audition and vision: Evidence for similar cognitive styles across modalities. *Acta Psychologica,* 138(2), 329-335.

Bronson, G.W. (1991). Infant differences in rate of visual encoding. *Child Development, 62*(1), 44-54.

Bruce, V. G., & Morgan, M. J. (1975) Violations of symmetry and repetition in visual patterns. *Perception* 4(3) 239 – 249.

Butler, J; & Rovee-collier, C (1989) Contextual gating of memory retrieval. *Developmental Psychobiology, 22(*6), 533-552

Casey, B.J. ; Cohen, Jonathan D. ; Jezzard, Peter ; Turner, Robert ; Noll, Douglas C. ; Trainor, Rolf J. ; Giedd, Jay ; Kaysen, Debra ; Hertz-Pannier, Lucy; & Rapoport, Judith L. (1995). Activation of prefrontal cortex in children during a nonspatial working memory task with functional MRI *Neuroimage, 2*(3), 221-229

Chugani, Harry T. ; Phelps, Michael E.; & Mazziotta, John C. (1987) Positron emission tomography study of human brain functional development. *Annals of Neurology, 22*(4), 487-497

Cohen, J. D., & Servan-Shreiber, D. (1992) Context, cortex, and dopamine: a connectionist approach to behavior and biology in schizophrenia. *Psychological Review, 99(1),* 45-77.

Cohen, JD ; Barch, DM ; Carter, C ; & Servan-Schreiber, D (1999). Context-processing deficits in schizophrenia: Converging evidence from three theoretically motivated cognitive tasks. *Journal of Abnormal Psychology, 108*(1), 120-133

Colombo, J. (1995). On the neural mechanisms underlying developmental and individual differences in infant fixation duration: Two hypotheses. *Developmental Review, 15,* 97-135

Colombo, J. & Cheatham (2006) The emergence and basis of endogenous attention in infancy and early childhood. *Advances in Child Development and Behavior, 34*, 283–322

Colombo J., & Mitchell, D. W. (1990). Individual differences in early visual attention: Fixation time and cognitive processing. In J. Colombo & J. Fagen (Eds.) *Individual differences in Infancy* (pp. 193-225). Hillsdale, NJ: Erlbaum.

Colombo, J. & Richman, W.A. (2002). Infant timekeeping: Attention and temporal estimation in 4-month-olds. *Psychological Science, 13*(5), 475-479.

Colombo, J., Frick, J., & Ryther, J., & Gifford, J. (1996). Four-month-old's recognition of complementary-contour forms. *Infant Behavior and Development, 19(1),* 113-119.

Colombo, J., Mitchell, D. W., & Horowitz, F. (1988). Infant visual attention in the paired-comparison paradigm: Test-retest and attention-performance relations. *Child Development, 59(5),* 1198-210.

Colombo, J., Mitchell, D. W., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant attention: Are short lookers faster processors or feature processors? *Child Development*, *62*, 1247-1257.

Colombo, J., Mitchell, D.W., O'Brien, M., & Horowitz, F.D. (1987). The stability of visual habituation during the first year of life. *Child Development, 58*(2), 474-487.

Colombo, J., Richman, W. A., Shaddy, D. J., Greenhoot, A. F., & Maikranz, J. (2001). HR-Defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. *Child Development, 72*, 1605-1616.

Cornish, KM ; Manly, T ; Savage, R ; Swanson, J ; Morisano, D ; Butler, N ; Grant, C ; Cross, G ; Bentley, L ; Hollis, CP (2005). Association of the dopamine transporter (DAT1) 10/10-

repeat genotype with ADHD symptoms and response inhibition in a general population sample. *Molecular Psychiatry, 10*(7), 686-698

Cuevas, K. & Bell, M. A. (2010) Developmental progression of looking and reaching performance on the A-not-B task. *Developmental Psychology, 46*(5), 1363(9)

Cuevas, K. ; Bell, M.A. ; Calkins, S.D. & Marcovitch, S. (2012) Electroencephalogram and heart rate measures of working memory at 5 and 10 months of age. *Developmental Psychology, 48*(4), 907(11)

Deoni, S.C. ; Mercure, E.; Blasi, A.; Gasston, D.; Thomson, A.; Johnson, M.; Williams, S.C.; & Murphy, D.G. (2011), Mapping infant brain myelination with magnetic resonance imaging. *Journal of Neuroscience, 31*, 784–791

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development,* 56, 868-883.

Diamond, A. (1990). The development and neural bases of memory functions as indexed by the AB and delayed response tasks in human infants and infant monkeys. In A. Diamond (Ed.), *The Development and Neural Bases of Higher Cognitive Functions* (pp. 267-309). New York: New York Academy of Sciences Press.

Diamond, A. (1996). Evidence for the importance of dopamine for prefrontal cortex functions early in life. *Philosophical Transactions of the Royal Society of London B, 351***,** 1483-1494

Diamond, A. & Goldman-Rakic, (1989) Comparison of human infants and rhesus monkeys on Piaget's AB□ task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research, 74*, 24–40

Diamond, A ; Prevor, M B ; Callender, G ; Druin, D P (1997) Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Research in Child Development, 62*(4), i-v, 1-208

Dietrich A; Frederick DL; & Allen JD. (1997). The effects of total and subtotal prefrontal cortex lesions on the timing ability of the rat. *Psychobiology, 25*, 191-201

Fagen, J.; Prigot, J.; Carroll, M.; Pioli, L.; Stein, A.; & Franco, A. (1997). Auditory context and memory retrieval in young infants. *Child Development. 68*(6), 1057-1066

Fossella, J.; Sommer, T.; Fan, J.; Wu, Y.; Swanson, J.; Pfaff, D.; Posner, M. (2002) Assessing the molecular genetics of attention networks. *BMC Neuroscience, 3*(1), 14

Freeseman, L., Colombo, J., Coldren, J. (1993) Individual differences in infant visual attention: Four-month-old's discrimination and generalization of global and local stimulus properties. *Child Development, 64(4),* 1191-1203.

Frick, J., & Colombo, J. (1996). Individual differences in visual attention: Recognition of degraded visual forms by four-month—olds. *Child Development, 67(1),* 188-204.

Frick, J., Colombo, J., & Saxon, T. (1999) Individual and developmental differences in disengagement of fixation in early infancy. *Child Development, 70(3),* 537-548.

Gizer, IR ; & Waldman, ID (2012). Double dissociation between lab measures of inattention and impulsivity and the dopamine transporter gene (DAT1) and dopamine D4 receptor gene (DRD4). *Journal of Abnormal Psychology, 121*(4), 1011-1023

Guy, M., Reynolds, G.D., & Zhang, D. (2013). Visual attention to global and local stimulus properties in 6-month-old infants: Individual differences and event-related potentials. *Child Development, 84*(4), 1392-1406.

Han, Shihui ; Fan, Silu ; Chen, Lin ; & Zhuo, Yan (1997). On the different processing of wholes and parts: A psychophysiological analysis. *Journal of Cognitive Neuroscience*, *9* (5), 687-698

Hay, J.F., & Lany, J. (2012). Statistical learning begets learning in early language development. In P. Rebuschat & J. Williams (Eds.)Statistical Learning and Language Acquisition. Mouton de Gruyter.

Holmboe, K ; Nemoda, Z ; Fearon, RMP ; Csibra, G ; Sasvari-Szekely, M ; & Johnson, MH (2010) Polymorphisms in dopamine system genes are associated with individual differences in attention in infancy. *Developmental Psychology, 46*(2),.404-416

Holmboe, K.K., Pasco Fearon, R.M., Csibra, G., Tucker, L.A., & Johnson, M.H. (2008). Freeze-frame: A new infant inhibition task and its relation to frontal cortex tasks during infancy and early childhood. *Journal of Experimental Child Psychology, 100*(2), 89-114.

Jankowski, J., Rose, S., & Feldman, J. (2001) Modifying the distribution of attention in infants. *Child Development, 72(2),* 339-351.

Karrer, R., & Monti, L. A. (1995). Event-related potentials of 4–7 week-old infants in a visual recognition memory task. *Electroencephalography and Clinical Neurophysiology, 94*,414–424.

Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: A critical review *Psychological Bulletin, 112* (1), 24–38

Kirkham, N.A.; Slemmer, J.A.; & Johnson, S.P. (2002). Visual statistical learning in infancy: evidence for a domain general learning mechanism. *Cognition, 83*(2),B35-B42

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD, *Journal of Clinical and Experimental Neuropsychology, 24*, 781-791.

Kobayashi, T.; Hiraki, K.; & Hasegawa, T. (2005). Auditory–visual intermodal matching of small numerosities in 6-month-old infants. *Developmental Science, 8*(5), 409-419

Levitin, DJ ; & Menon, V (2005).The neural locus of temporal structure and expectancies in music: Evidence from functional neuroimaging at 3 tesla. *Music Perception, 22*(3), 563-575

Lewkowicz, DJ (2004). Perception of serial order in infants. *Developmental Science, 7*(2), 175-184

Locher, P., & Nodine, C. (1973) The influence of visual symmetry on visual scanning patterns. *Perception and Psychophysics, 13,* 408-412.

Luciana, Monica ; & Nelson, Charles A. (1998) The functional emergence of prefrontally-guided working memory systems in four- to eight-year-old children. *Neuropsychologia, 36*(3), 273-293

McCall, R.B. (1994). What process mediates predictions of childhood IQ from infant habituation and recognition memory? Speculations on the roles of inhibition and rate of information processing. *Intelligence, 18*, 107-125.

McCulloch, J.; Savaki, H.E.; & Sokoloff, L. (1982) Distribution of effects of haloperidol on energy metabolism in the rat brain. *Brain Research, 243*(1), 81-90

Moss, M., Colombo, J., Mitchell, D.W., & Horowitz, F.D. (1988). Neonatal behavioral organization and visual processing at three months. *Child Development, 59*(5), 1211-1220.

Nagy Z.; Westerberg H.; & Klingberg T. (2004) Maturation of white matter is associated with the development of cognitive functions during childhood. *Journal of Cognitive Neuroscience, 16*(17); 1227-33.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9,* 353-383.

Nelson, C. A., & Dukette, D. (1998). A cognitive neuroscience perspective on the relation between attention and memory development. In J. E. Richards (Ed.), *Cognitive Neuroscience of Attention: A developmental Perspective* .Psychology Press.

Nunez, P.L. (1981) *Electric fields of the brain: The neurophysics of EEG* (1st ed.)Oxford University Press, New York

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, 13, 25–42

Rescorla, R.A. & Wagner, A.R. (1972). A theory of Pavlovian conditioning.: variations in the effectiveness of reinforcement and nonreinforcement. In Black, A.H. & Prokasy, W.F. (Eds), *Classical Conditioning II: Current Research and Theory.* Appleton-Century-Crofts, New York, NY, pp. 64-99.

Reynolds, G. D., & Richards, J. E. (2005). Familiarization, attention, and recognition memory in infancy: An ERP and cortical source localization study. *Developmental Psychology, 41*, 598–615

Reynolds, G., Guy, M., & Zhang, D. (2011). Neural correlates of individual differences in infant visual attention and recognition memory. *Infancy, 16*(4), 368-391.

Richards, J.E. (2003). Attention affects the recognition of briefly presented visual stimuli in infants: An ERP study. *Developmental Science, 6*, 312-328

Richards, J. E., Reynolds, G. D., & Courage, M. L. (2010). The neural bases of infant attention. *Current Directions in Psychological Science, 19*(1), 41–46.

Rose, D. H., Slater, A., & Perry, H. (1986). Prediction of childhood intelligence from habituation in early infancy. *Intelligence, 10,* 251–263.

Rovee-Collier, C ; Schechter, A; Shyi, G.; & Shields, P. (1992). Perceptual identification of contextual attributes and infant memory retrieval. (Cognitive Processes Across the Life Span). *Developmental Psychology, 28*(2), 307(12)

Rueda, M R.; Rothbart, M.K.; Mccandliss, B.D.; Saccomanno, L.; & Posner, M.I. (2005) Training, maturation, and genetic influences on the development of executive attention *Proceedings of the National Academy of Sciences of the United States of America, 102*(41), 14931-6

Slater, A ; Brown, E ; & Badenoch, M (1997) Intermodal perception at birth: Newborn infants' memory for arbitrary auditory-visual pairings. *Early Development & Parenting, 6*(3-4)

Stoecker, J. J., Colombo, J., Frick, J. E., & Allen, J. R. (1998). Long- and short-looking infants' recognition of symmetrical and asymmetrical forms. *Journal of Experimental Child Psychology, 71(1),* 63-78.

Stormer, VS ; Passow, S ; Biesenack, J ; & Li, SC (2012). Dopaminergic and cholinergic modulations of visual-spatial attention and working memory: Insights from molecular genetic research and implications for adult cognitive development. *Developmental Psychology, 48*(3), 875-889

Tamis-LeMonda, C. S., & Bornstein, M. H. (1989). Habituation and Maternal Encouragement of Attention in Infancy as Predictors of Toddler Language, Play, and Representational Competence. *Child Development*, 60, 738-751.

Thatcher, R.W; Krause, P.J; & Hrybyk, M (1986) Cortico-cortical associations and EEG coherence: A two-compartmental model. *Electroencephalography and Clinical Neurophysiology, 64*(2), 123-143

Thorpe, L.A.; & Trehub, S.E. (1989). Duration illusion and auditory grouping in infancy. *Developmental Psychology, 25*(1), 122(6)

Treisman, A., & Gelade, G. (1980) A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Tsekhmistrenko, T. ; Vologirov, A. ; Vasil'eva, V. ; Shumeiko, N. (2005). Quantitative changes in the fibroarchitectonics of the human cortex from birth to the age of 12 years. *Neuroscience and Behavioral Physiology, 34*(9), 983-988

Turati, C ; Di Giorgio, E ; Bardi, L ; Simion, F (2010) Holistic face processing in newborns, 3-month-old infants, and adults: Evidence from the composite face effect. *Child Development, 81*(6),1894-1905

Usher, M. & McClelland, J.L. (2001) The time course of perceptual choice: The leaky, competing, accumulator model. *Psychological Review*, 108(3), 550-592.

Vaughn, M.G.; Delisi, M.; Beaver, K.M.; & Wright, J.P. (2012). Dopaminergic polymorphisms and educational achievement: Results from a longitudinal sample of Americans. *Developmental Psychology, 48*(4), 932(7)

Wolfe, C.D. & Bell, M.A. (2004) Working memory and inhibitory control in early childhood: Contributions from electrophysiology, temperament, and language. *Developmental Psychobiology, 44*, 68–83

Wolfe, C.D. & Bell, M.A. (2007) The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. *Brain and Cognition, 65*, 3–13